AD-A190 970 MODELLING SEASONALLY FREEZING GROUND CONDITIONS(U) 1/1
BRISTOL UNIV (ENGLAND) M G ANDERSON ET AL. NOV 87
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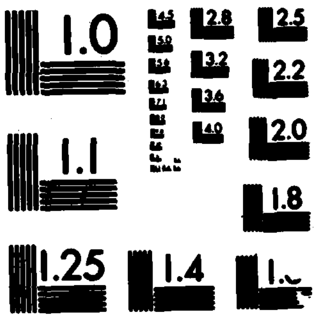

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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Contents

1.1 Introduction

This report covers the work done for contract number 45-87-C-0036 from April (inception of the project) through to November 1987 and discusses the model structure currently being developed and the visit to CRREL in October 1987.

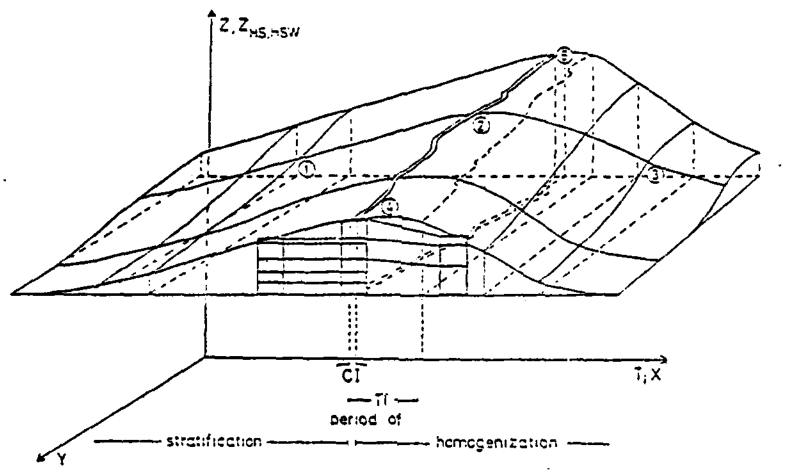
1.2 Aim

This project's aim is

To model the spatial distribution of snowcover in areas experiencing seasonally frozen ground.

1.3 Operational objectives

SNOWM1, the model that is currently being developed is an attempt to mathematically model and thereby represent, the distribution of snow within a catchment over the snow season. Figure 1 ~~(Rau and Hermann, 1982)~~ is a graphical representation of the snowcover distribution over the snow season, which SNOWM1 will attempt to mathematically reproduce. Figure 1 considers a plane model slope the position and elevation of which are defined by the coordinates X, Y and Z. X and Z are the *axes of rotation*, for variations of slope angles and azimuths. The evolution in time of a snow profile at a given point (Xy/Yy) on the slope is shown along the T-axis (points 1,2 and 3). Snowprofile variation with elevation is demonstrated for any time, along the Y-axis (points 4,2 and 5). It is this situation, graphically demonstrated by figure 1, that, when applied to a catchment, the model SNOWM1 is being developed.



HS	Snowdepth
HSW	Water equivalent of snow depth
CI	Critical interval, meltwater production is initiated.
TI	Transition interval, runoff formation is initiated

Figure 1: Schematic model of an alpine snowcover store (Rau and Hermann, 1982)

2.1 Model Structure

The basic structure of SNOWM1 is shown in figure 2. SNOWM1 operates within cells which are subdivisions of the total catchment area. The energy values of net, long- and short-wave radiation, sensible heat transfer and latent heat transfer are calculated for a centre point of each cell using the thermal model tstm (Balick et al. (1981)), which has been converted into a subroutine. The energy values are then used in equations 1-5 (Table 1) along with precipitation data to calculate the energy available for snowmelt and, if snowmelt occurs, the amount of snow that melted and its water equivalent. SNOWM1 is being written in FORTRAN-77 and is being developed on a SUN 3/60 workstation. The program code and the catchment subdivision are discussed in more detail below.

2.2 Program code

The program, SNOWM1 now consists of three sections - the main or control section, which is the slightly modified *SNOWM of Anderson* and Sambles (July 1987), and two subroutines. The subroutines are: (i) tstm which calculates the energy values of long- and short-wave radiation, sensible heat transfer and latent heat transfer and (ii) energy, which calculates the energy available for melt.

(i) Tstm: Tstm has been converted into a subroutine; its basic structure is unchanged. The conversion of tstm into a subroutine is due primarily to the help of Dr. Randy Scoggins (Environmental Laboratory, Vicksburg), who was involved in the initial development of tstm. Tstm has been slightly modified so that it will accept, at a minimum, one data input per day. Output values are then interpolated between one data input and the next, i.e. if data measurement occurred at 0930 on day 1 and 1100 on day 2 values will be interpolated for 0930 to 1100. Interpretation for the majority of the variables is linear, however for variables such as solar insolation, which have zero night values, the interpretation is non-linear.

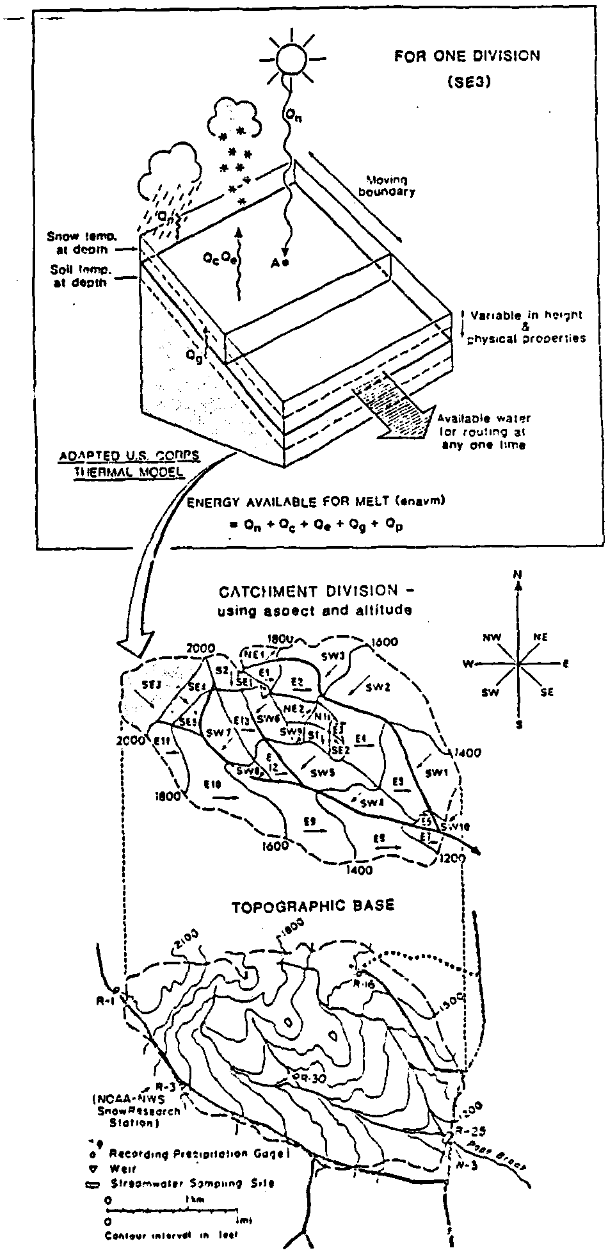


Figure 2: Basic structure of the catchment snow model SNOWM1

Table 1 : Equations (a) and model structure (b) for physically based Bristol model of snowcover

(a) EQUATION NUMBER	NOTATION (a) ORIGINAL (from July report) (b) SNOWM (using TSTM)	VARIABLE CORRESPONDENCE AND UNIT - underlined variables are taken from TSTM
1	(a) $R_n = S\downarrow - S\uparrow + L\downarrow - L\uparrow$ (b) NETRAD = ISOL - (ISOL - IABSOR) + IATERM - IBGR	R_n = NETRAD ($JM^{-2}s^{-1}$) $S\downarrow$ = ISOL (WM^{-2}) $S\uparrow$ = $\underline{\text{(ISOL-IABSOR)}}$ (WM^{-2}) $L\downarrow$ = $\underline{\text{IATERM}}$ (WM^{-2}) $L\uparrow$ = $\underline{\text{IBGR}}$ (WM^{-2}) $1\ JM^{-2}s^{-1} = 1\ WM^{-2}$
2	(a) enavm = R_n+enc+ene+eng+enp (b) enavm = NETRAD+IHTERM+IDTERM+GTERM+PTERM = Qn + Qc + Qe + Qg + Qp	enavm = ENAVM ($JM^{-2}s^{-1}$) enc = $\underline{\text{IHTERM}}$ (WM^{-2}) ene = $\underline{\text{IDTERM}}$ (WM^{-2}) eng = $\underline{\text{GTERM}}$ (WM^{-2}) enp = PTERM ($JM^{-2}s^{-1}$)
3	(a) $M = \frac{enavm}{\mathcal{L}\rho sB}$ (b) MELTR = ENAVM/(LHEATF*DENSN*COEFB)	M = MELTR (M.water s^{-1}) enavm = ENAVM ($JM^{-2}s^{-1}$) $\mathcal{L}$ = LHEATF (Jkg^{-1}) ρs = DENSN (kgM^{-2}) B = COEFB
4	(a) $Qp = \rho w Cp\ (Tr-Ts)\ Pr/1000$ (b) PTERM = 86400 [DENW*HCAPW*(RTEMP-STOR(5,1))*PRATE]	$Qp(kJM^{-2}day^{-1})$ = PTERM ($JM^{-2}s^{-1}$) ρw = DENW (Kgm^{-3}) cP = HCAPW ($kJkg^{-1}\ oC^{-1}$) Tr = RTEMP (^oC) Ts = $\underline{\text{STOR(5,1)}}$ (^oC) Pr = PRATE (mmday^{-1}) *86400 to convert $kJM^{-2}\ day^{-1}$ to $JM^{-2}s^{-1}$
5	(a) $Sntt = \frac{\Delta t.enavm}{cp\rho s\ d}^{t-1}$ (b) STOR(5,1) = (DELTS*ENAVM)/(HCAPSN*DENSN*DEPTH)	sntt = STOR(5,1) (K) Δt = DELTS (s) enavm = ENAVM ($JM^{-2}s^{-1}$) cp_s = HCAPSN ($Kkg^{-1}K^{-1}$) ρs = DENSN ($kgM.Snow^{-3}$) d = DEPTH (M)

The conversion of tstm into a subroutine is vital as it enables the energy values of net radiation, sensible heat transfer and latent heat transfer to be calculated for any slope with any aspect and so avoids the necessity of measuring these values in the field (although their measurement for validation purposes is still necessary).

Table 2 demonstrates two of the output variables, solar insolation and surface temperature, that tstm calculates. These results were calculated from data similar to that expected at W3 during the melt season and were run on a pre-conversion-to-a-subroutine tstm. The results also demonstrate the importance of aspect on solar insolation and surface temperature. Maximum solar radiation is at 1300 and is 721 Wm^{-2} on a south facing slope and zero Wm^{-2} on a north facing slope. Similarly, surface temperatures are at a maximum of +7.5 and -2.6°C on south and north-facing slopes respectively. The difference in night-time temperatures is not so great, especially in early morning, by which time the differential effect of the daytime solar radiation has disappeared.

SNOWM uses the averaged values of the energy variables calculated by tstm. Tstm calculates the energy values at a desired interval (which can be altered) and prints these out if required at another desired interval, e.g. hourly, half-hourly, or 15 minute intervals. Tstm then puts these variables (at the print-out time interval) into a matrix (datmix). An average value for each variable is then calculated and it is these averaged daily (data-measurement-period to data-measurement-period) values that are passed across to SNOWM. It should be possible to alter the print-out interval time to achieve greater resolution of variables at key times of the day, i.e. sunrise and sunset.

Tstm requires many initial inputs. It is hoped that most of these inputs, e.g. the soil and/or snow moisture, thermal conductivity, temperature profile and the snow albedo, can be converted into self-generating variables once initialized at the start of the model run, or after extreme events. This would result in a decrease in input data confining the daily input mainly to meteorological data.

(a) Solar insolation (Wm^{-2})

Hours	North	South	East	West
1.00	0	0	0	0
2.00	0	0	0	0
3.00	0	0	0	0
4.00	0	0	0	0
5.00	0	0	0	0
6.00	0	36	8	0
7.00	0	19	108	0
8.00	0	0	220	0
9.00	0	0	321	180
10.00	0	0	401	273
11.00	0	0	603	461
12.00	0	0	627	519
13.00	0	0	721	638
14.00	0	0	642	603
15.00	0	0	522	522
16.00	0	0	366	396
17.00	0	0	232	287
18.00	0	0	42	99
19.00	0	0	0	0
20.00	0	0	0	0
21.00	0	0	0	0
22.00	0	0	0	0
23.00	0	0	0	0
0.00	0	0	0	0

(b) Surface temperature (^{o}C)

1.00	-14.1	-14.1	-14.1	-14.1
2.00	-13.3	-13.3	-13.3	-13.3
3.00	-11.3	-11.3	-11.3	-11.3
4.00	-10.3	-10.3	-10.3	-10.3
5.00	- 8.4	- 8.4	- 8.4	- 8.4
6.00	- 7.5	- 7.4	- 7.0	- 7.5
7.00	- 5.9	- 4.6	- 5.7	- 5.9
8.00	- 5.1	- 2.3	- 5.1	- 4.1
9.00	- 4.5	0.0	- 4.5	- 1.9
10.00	- 3.7	2.0	- 3.6	0.3
11.00	- 3.4	4.9	- 3.3	3.1
12.00	- 3.3	5.7	- 3.3	4.2
13.00	- 3.1	7.5	- 2.0	6.4
14.00	- 2.6	7.5	- 2.6	6.9
15.00	- 2.9	5.8	- 2.8	5.6
16.00	- 4.7	4.0	- 4.7	4.2
17.00	- 5.6	0.8	- 5.6	1.4
18.00	- 8.5	- 5.3	- 8.5	- 4.4
19.00	-19.2	- 8.1	-10.2	- 8.0
20.00	-12.2	-10.6	-12.2	-10.6
21.00	-14.0	-12.8	-14.0	-12.8
22.00	-15.6	-14.7	-15.6	-14.8
23.00	-16.6	-15.9	-16.6	-16.0
0.00	-17.9	-17.4	-17.9	-17.5

Table 2: Solar insolation and snow surface temperature for Julian day 91 (April 1st and 2nd), latitude 44° 20', 10° slope with different aspects.

(ii) Energy: This calculates the energy input into a ripe snowpack by rainfall (equation (4), Table 1). This value is then input along with the energy variables calculated by tstm, into equation (2), Table 1, which calculates the energy available for melt.

iii) SNOWM: In the previous report (Anderson and Sambles, July 1987) the logic for the proposed snowmodel, SNOWM, was presented (Figure 3 and chapter C), This logic has now been modified, the main inclusion being that of the question "Is there any precipitation?" before every use of "Is the air temperature greater than or less than $0^{o}C$?"

Another addition was that of equation (6) (Male and Granger, 1978) to calculate the rate of change of snow temperature when rain falls on a snowpack with a temperature of below ^{o}C

Equation 6:

$$\frac{dT_m}{dt} = \frac{P\rho\,[C_p\,T_p + L_f - C_{pi}\,T_m]}{C_{pi}\,\rho_i\,d}$$

T_m mean snow temperature (^{o}C)
P precipitation rate ($mm\,day^{-1}$)
ρ density of water (kgm^{-3})
C_p heat capacity of water ($kJ\,kg^{-1}\,{}^{o}C^{-1}$)
T_p temperature of the rain (^{o}C)
L_f latent heat of fusion ($kJ\,kg^{-1}$)
C_{pi} heat capacity of snow ($kJ\,kg^{-1}\,{}^{o}C^{-1}$)
ρ_i mean snow density (kgM^{-3})
d snow depth (M)

The logic in SNOWM will call either a tstm subroutine with soil data characteristics or a tstm subroutine with snow characteristics. It should be possible to model snow on top of soil because tstm operates with a layered approach to the calculation of the temperature profile, i.e. one layer can have snow characteristics, another soil.

At present SNOWM consists of several assumptions. These are recognised and will be dealt with in the future:

(1) Tstm gives a choice of three bottom boundary conditions:-

i) A constant heat temperature at the bottom boundary (no heat flux through the bottom.

ii) A constant heat flux at the bottom boundary (no airspace beneath the bottom).

iii) A constant heat flux at the bottom boundary and an additional constant temperature radiating surface below boundary bottom (an airspace beneath bottom).

At the present, in order to keep the modelling situation as simple as possible condition (i) will be said to be operating at the bottom boundary, i.e. there is no heat flux through the bottom boundary and therefore GTERM (energy flux from ground to snow) is zero.

(2) SNOWM calculates the available water for routing. Once this available water has been generated, then it will have to either be translocated elsewhere within the same cell or in adjacent cells. Freezing and subsequent remelt can occur at any point in the translocation process. SNOWM1 could be coupled to a physically based distributed hydrological model.

(3) The snowpack is assumed homogeneous with depth and area within each cell, i.e. there is no stratification of soil particles or ice layers and/or no density changes. Density changes with depth as does the occurrence of ice or dirt lenses or layers. Density also changes with time, as does albedo. This is not modelled at present.

(4) The penetration of solar radiation through the snow is zero, i.e. all the solar energy is assumed to act on the surface and not be conducted down through the snowpack. The radiation intensity at any depth can be calculated by:

$$I_z = I_o \exp(-bz) \quad \text{(Male and Grey, 1981)}$$

I_z = radiation intensity (kWm^{-2}) at any depth, z (cm)

I_o = radiation intensity at snow surface (kWm^{-2})

b = extinction coefficient

(5) All the solar radiation is direct, non diffuse. Khale (1977) gives an equation for diffuse solar radiation:

$$Sdiff = 0.05S + 0.10\,(1 - COSz)S$$

Sdiff amount of incoming radiation that is diffusely scattered by the atmosphere.

S Solar radiation absorbed by ground when cloud free.

z Zenith angle of sun as a function of time of the day and year

(6) The expression $\frac{dU}{dt}$ for the rate of change of internal (or stored) energy per unit area of snowcover is omitted from equation (2). Internal energy consists of a component for the solid, liquid and vapour phase of the snow pack and can be calculated (Male and Grey, 1981).

(7) Snowmelt water equivalent (in metres) is calculated from depth of snow melted (in metres) divided by the density of fresh snow, 100 kgm^{-3}, i.e. 1 cm of snow is equivalent to 1 mm of water. This is an established method used by the Canadian Atmospheric Service. Snow density, as discussed in assumption (3), varies with age and depth and therefore, especially during the melt season when refreezing is active and the snow is old, the snow density will not always be 100 kgm^{-3}.

(8) The action of freezing rain on the snowpack has not been accounted for.

(9) The effect of vegetation on snowcover distribution is omitted. Vegetation has an important effect on snow accumulation interception and on radiation values, shading and drainage.

(10) "The complex nature of the transport and deposition process and the large number of factors affecting them defies development of a generalized physically-based mathematical model for describing areal snowcover accumulation and distribution." McKay and Gray (1981).

The modelling of snow accumulation in SNOWM takes no account of drifting, etc., and applies point data from the precipitation stations to the whole of W3 (similar problems exist with all the point meteorological data but are unavoidable. The whole catchment cannot be instrumented and SNOWM1 is being designed for relatively poorly instrumented catchments). Point precipitation data from the sites at W3 will be used as the precipitation input for the whole of W3. The use of point data to describe a large area has problems as no account is taken of the effect of wind on snow distribution (drifting) vegetation interception, topographic variation and redistribution by wind once the snow has fallen (drifting). Goodison, Ferguson and McKay (1981) summarize the problems of point snowfall measurements:

> "Point snowfall measurements may be used to estimate depths over relatively large areas, when the accumulation period is long, the terrain is flat, the snowfall is steady and major redistribution by wind does not occur. Conversely, when the accumulation period is short the terrain is fairly rugged and the snowfall is showery (e.g. lake effect snowfall) point, measurements will provide reliable estimates of depth over only relatively small areas."

There are wind and speed measurements (again they are point measurements) available for W3 and with a knowledge of the topography and vegetation cover at W3 it should be possible to create a rough drifting or snow accumulation hazard map, i.e. each cell is categorized for its potential for drifting, interception, etc., at different wind speeds, based on its topography and vegetation.

2.3 Catchment subdivision

The subdivision of the catchment into smaller areas, cells, is demonstrated in figure 2. This subdivision is based on aspect and altitude with, for the present, an arbitrary choice of every 200 m. contour. Each cell will have a

mean altitude, slope and soil type, etc., and conditions withi ach cell are, for the present, assumed uniform. Once SNOWM is in operation it is expected that several adjustments will have to be made in the initial catchment subdivision. For example, there may be an optimum cell size above which to assume uniform conditions within each cell leads to unacceptable errors. The final catchment subdivision will be based on vegetation cover as well as aspect and altitude because vegetation has a large effect on snowcover distribution, as well as being spatially easy to demark.

3.1 CRREL Visit, 5 - 9 October 1987

The visit was primarily to meet Dr. Tim Pangburn (CRREL) and Dr. Randy Scoggins (Environmental Laboratory, Vicksburg). Three days were spent with Randy Scoggins, using the CRREL PRIME, converting tstm into a subroutine. The feasibility of modelling a multilayered snow/soil tstm with a vertical moving snow boundary or a multilayered snow/ice lens tstm with the ability to model both growth and decay of the ice lens or snow layer was discussed with Randy Scoggins. This should be possible to do and if done solves the vertical moving boundary problem.

A morning was spent up at W3 with Tim Pangburn. R-3, R-25, R-16, W-16, W-3 and the frost tube sites were visited in W3 in addition to W-7 and R-19. The feasibility of a field study at W3 during the snowmelt season (March-April) was discussed with Tim Pangburn. Further data relating to W3 was collected from Tim Pangburn, i.e. soil maps and topographic base maps. The use of Tim Pangburn's current mixing model research into water temperatures at W3 as another means of calculating volume of generated snowmelt was discussed. A record of snowcover distribution during the snowmelt season is needed to verify SNOWM1. Unfortunately this is not available and will have to be collated during the next melt season at W3. An alternative, or addition to this, is the use of SPOT satellite imagery as a means of delineating snowcover extent. The use of SPOT to show snowcover extent was demonstrated by Nancy Le Pontin. Table 3 shows the validation and input data required for SNOWM1. A discussion was held with Dr. Rachel Gordon who is also working on the thermal modelling of snowmelt, although on a smaller, tank-track, size.

Table 3

Input Data

Cloud type
Cloud cover
Instrument shelter height
Air temperature
Relative humidity
Wind speed
Slope angle
Slope aspect
Latitude
Ground temperatures at depth
Surface thermal emissivity
Surface albedo
Snow/soil thermal diffusivity
Snow/soil heat conductivity
Snow/soil saturation
Precipitation
Cell area

Verification Data

(1) Record of snowcover distribution and depth during year, especially during the melt season. Map, aerial photography or satellite sources.

(2) Snow and soil temperature measurements on the surface and at depth.

(3) Energy values generated by tstm, i.e. solar radiation greybody radiation, atmospheric infrared emission, surface absorption, sensible heat and latent heat.

(4) Volume of snowmelt. Runoff data at W-3 and W-16, snowmelt lysimeter information at R-3 and Dr. Tim Pangburn's water temperature mixing model data.

(5) Data is needed for the verification of the proposed self-generating variables of albedo, emissivity, thermal diffusivity, saturation and the snowpack and/or soil temperature profiles.

4.1 Proposed schedule of work

December 1987

- Familiarization with SUNs.
- Final incorporation of tstm into SNOWM1. Initial runs of SNOWM1.
- Reading on field techniques and snow cover distribution mapping.

January - March 1988

- Detailed topographic base subdivision.
- Continuation of the testing of SNOWM1, identifying potential areas of field interest.
- Finalisation of field schedule and logistical organisation, with Dr. Tim Pangburn.

Late March - April 1988

- Field acquisition of snowcover distribution and snow depth data during the melt period at W3. Initial observation of the effect of vegetation on snowcover distribution.

5.1 References

Anderson, M.G. and Sambles, K.M. (1987). Modelling seasonally freezing ground conditions: First Interim Report. European Research Office, U.S. Corps of Engineers, London, England.

Balick, L.K., Link, L.E. Scoggins, R.K. and Solomon, J.L. (1981). Thermal modelling of terrain surface elements. Technical Report EL-81-2, prepared by the Environmental Laboratory, Waterways Experiment Station, in collaboration with Mississippi State University, for the U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Goodison, B.E., Ferguson, H.L. and McKay, G.A. (1981). In: Handbook of Snow, D.M. Gray and D.H. Male (eds.), Pergamon Press, Oxford, 191-275.

Khale, A.B. (1977). A simple model of the earth's surface for geologic mapping by remote sensing. J. Geophys. Res., 82, 11, 1673-1680.

Male, D.H. and Granger, R.J. (1978). Energy mass fluxes at the snow surface in a prairie environment. In: Proc. Modelling of Snow Cover Runoff, S.C. Colbeck and M. Ray (eds.), U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 26-28 September 1978, 101-124.

Male, D.H. and Gray, D.M. (1981). Snowcover ablation and runoff. In: Handbook of Snow. D.M. Gray and D.H. Male (eds.), Pergamon Press, Oxford, 360-436.

McKay, G.A. and Gray, D.M. (1981). The distribution of snowcover. In: Handbook of Snow, D.M. Gray and D.H. Male (eds.), Pergamon Press, Oxford, 153-191.

Rau, R.G. and Herrmann, A. (1982). Variations in the properties of Alpine snow-cover stores. Hydrol. Aspects of Alpine and High Mt. Areas, IAHS Publ. No. 138, 91-100.

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